WRIGHT & CRATTY

Test of Gould Storage Battery

Electrical Engineering

B S

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TEST OF GOULD STORAGE BATTERY

BY

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THESIS

For the Degree of Bachelor of Science
in Electrical Engineering

COLLEGE OF ENGINEERING
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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

PAUL JONES CRATTY and MILTON RALEIGH WRIGHT

ENTITLED TEST OF GOULD STORAGE BATTERY

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Electrical Engineering

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INTRODUCTION.

The storage battery in most general use is of the Faure pasted plate type. The Gould battery owned by the Department of Electrical Engineering at the University of Illinois is of the Plante or formed plate type. This battery has been in operation two years, one year as part of the Gould Storage Battery Exhibit at the St. Louis Exposition and one year at the University of Illinois. When the battery was installed at the University efficiency tests run at the different discharge rates in connection with a thesis entitled Installation of a Gould Storage Battery. Since then the battery has been operated under all possible conditions but especially for calibrating instruments. Because the battery has been operated under such a wide range of conditions it was thought advisable to make a thorough commercial test of it and also to have it worked up into the best possible condition. To accomplish this it was thought advisable to assign as a Thesis.

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DESCRIPTION OF GOULD STORAGE BATTERY.

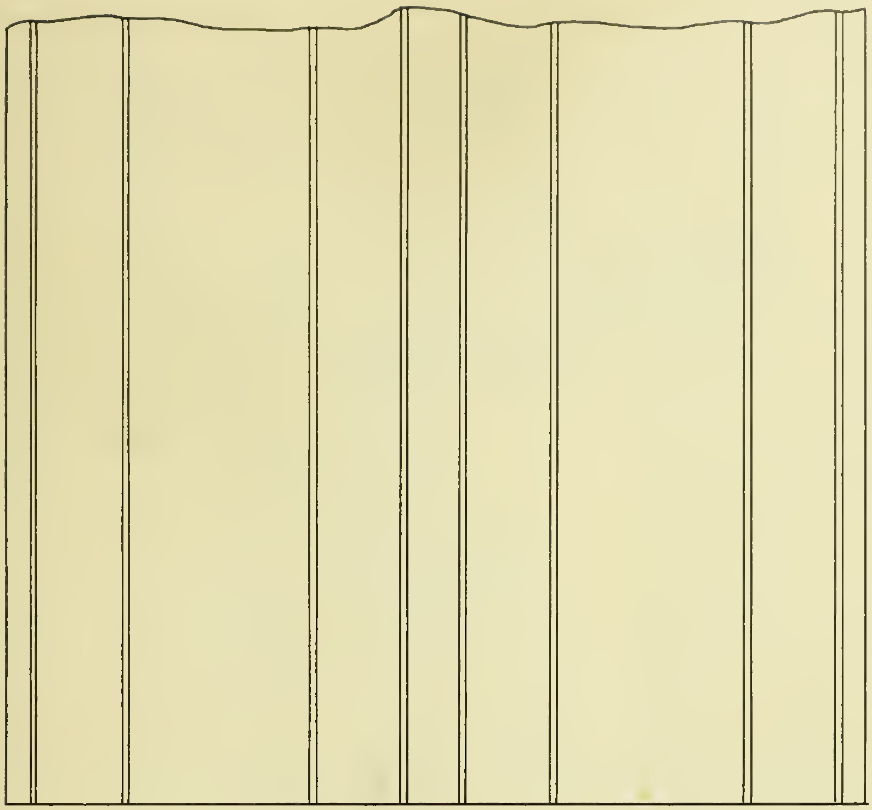
The Gould Storage Battery installed in Room 103 in the basement of the Electrical Engineering Laboratory is made up of 60 cells placed in three rows of 20 cells each. The pedestals upon which the cells are placed are built of brick and covered with glazed white tile. The construction and dimensions of the pedestals are shown by diagram 1. Starting with cell No. 1 at the switch board end of the battery there are in the outer row 10 end cells connected in series by means of reinforced bus bars. The remainder of this row consists of 10 cells, numbered from 11 to 20, in simple series connection. Returning to the switch board end the second row of cells is numbered from 21 to 40 away from the switch board. This row is simply connected in series. In the last row the cells number 41 to 60 and numbers run toward the switch board. Numbers 41 to 50 are connected in series, from 51 to 60 are end cells arranged so they may be connected in series or in multiple. This arrangement and numbering of cells has the advantage that it brings both end and multiple cells to the ends of the battery, also to shorten as much as possible the leads running to the switch board.

Each cell consists of a one inch oak tank lined with six pound sheet lead. Details and dimensions of tank and plates are shown in diagram No. 2. Each cell contains three positive, two negative and two one-half negative Gould Type O plates.

The Gould Type O plate is of the Plante type in the manufacture of which the spinning principle is used, producing

the large increased surface. No lead is removed from the blank plate. The circular disc entering at each end of the section leaves an unspun portion which anchors each individual rib to the main cross bar at both ends, a very fine line or web remaining through the center of the plate. Where the two sections join, the two half diamonds of unspun lead form cross bars of solid conducting material traversing the middle of the plate. A cross section of a plate is shown in diagram No. 2. Both positive and negative plates are formed from electro chemically pure lead. The half negative used on the outside is spun only on one side and by this means weight and cost of forming is reduced very materially. If new plates were added to this battery the half negative plates must be moved over to the outside of the cell. This however would be necessary even if a full negative were used, for the side of the negative which is not used if spun would deteriorate very rapidly.

The tanks are each lined on four sides with glass plates which support the elements and prevent them from touching the lead lining and causing short circuits. The plates are insulated from each other by glass rods which are held in place at the bottom of the tanks by lead troughs and at the top by rubber spacers and projections on the plates.



PLAN AND END ELEVATION
OF
PEDASTAL FOR STORAGE BATTERY.

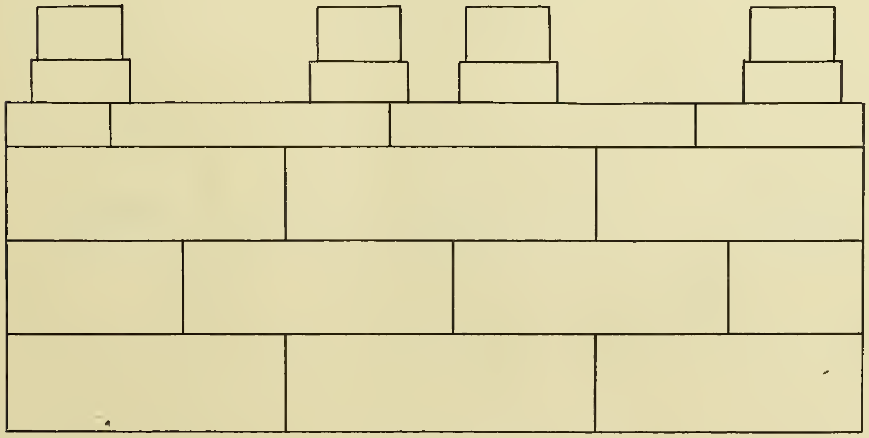
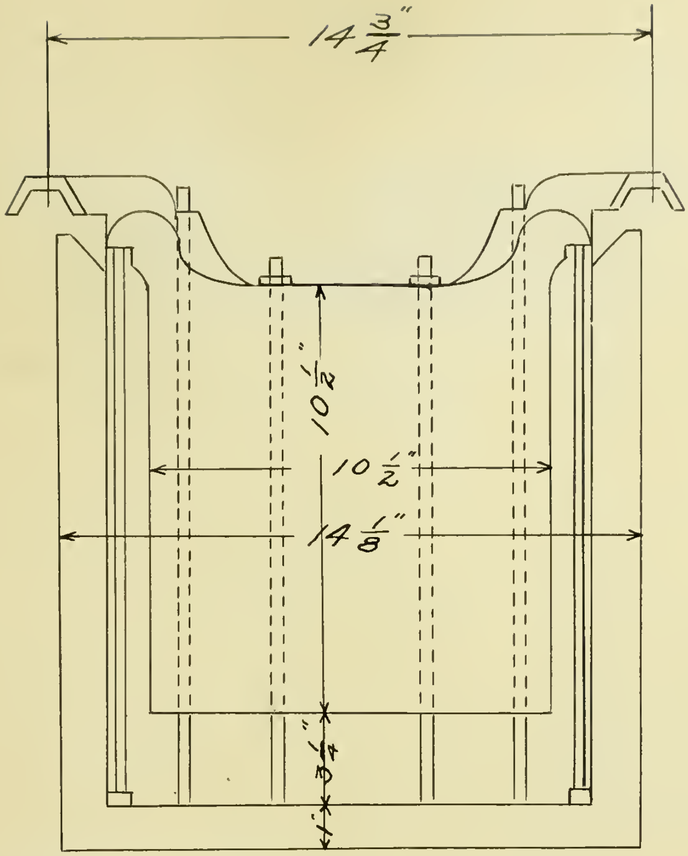


Fig. 1.



CROSS SECTION OF CELL

Fig. 2.

CROSS SECTION OF PLATE.

TESTS.

In making the test of the Gould Storage Battery the following were determined:

1. Capacity at normal and rapid discharge rates.
2. Interval virtual resistance.
3. Specific gravity variation of electrolyte.
4. Curves of charge and discharge.
5. Ampere hour efficiency at various discharge rates.
6. Watt hour efficiency at various discharge rates.

For a period of about three weeks before the starting of the test proper, the battery was given severe "workouts" at various discharge rates for the purpose of dissolving all sulphate that might be present and to bring all of the cells up to their full capacity. This was found to be necessary as several of the cells were in poor condition and, as they were not end cells, they could not be reached for individual treatment.

During part of the test the charging current was furnished by a shunt generator driven by an induction motor, and during the remainder of the test the charging current was furnished direct from the University Power Plant, with a lamp bank connected in series with the battery.

The cells were discharged through resistances consisting of banks of lamps and a rheostat capable of giving small resistance variations. The observations were made during two complete cycles of discharge and charge at various discharge rates. In each case the charging current was the same, namely, 30 amperes. Before taking the test observations, the battery was first brought up to full voltage of 162 volts at the switch

board and the product of 60 times the terminal cell voltage of 2.63 volts was due to the resistance drop in the leads to the switch board and the plug contacts on the switch board.

After charging was discontinued the switch board voltage immediately fell to 127 . Immediately after charge the battery was discharged until the terminal voltage of the cells reached 1.8 volts each. The battery was at once placed on charge again until the cell voltage was 2.63 volts, when it was again discharged at the same rate as before. The current was maintained constant on a given test by means of the rheostat previously mentioned.

Observations of battery voltage at the switch board, and cadmium readings at every sixth cell were taken throughout each cycle at intervals varying from 3 minutes at the commencement and end of each charge and discharge, to 30 minutes during that part when voltage was practically constant.

Observations of electrolytic density variations and temperatures of room and electrolyte were also taken. By the addition of distilled water, from time to time, while the cells were fully charged, the correct density of 1.225 was maintained. Two complete cycles each were run at discharge rates of 30,42, 60, and 120 amperes.

8 HOUR CHARGE #1.

Time	E	I	Hours	Ampere Hours	Watt Hours
6.40	126	30			
.43	128	"	.05	1.5	192
.45	130	"	.033	.99	129
.50	131	"	.083	2.5	328
7.00	131	"	.166	4.8	615
.15	131	"	.25	7.5	975
.45	132	"	.5	15.	990
8.00	133	"	.25	7.5	996
.30	133.5	"	.5	15.	2000
9.00	134	"	.5	15.	2010
.30	134.2	"	.5	15.	2010
10.00	135	"	.5	15	2020
.30	135.5	"	.5	15.	2025
11.00	136	"	.5	15.	2040
.30	137	"	.5	15.	2060
12.00	139	"	.5	15.	2080
.30	140	"	.5	15.	2100
1.00	148	"	.5	15	2210
.30	156	"	.5	15	2340
2.00	156.5	"	.5	15	2350
.30	159	"	.5	15	2380
.35	159.5	"	.083	2.5	400
2.40	162	"	.083	2.5	405
			8.000	239.7	32634

8 HOUR CHARGE #2

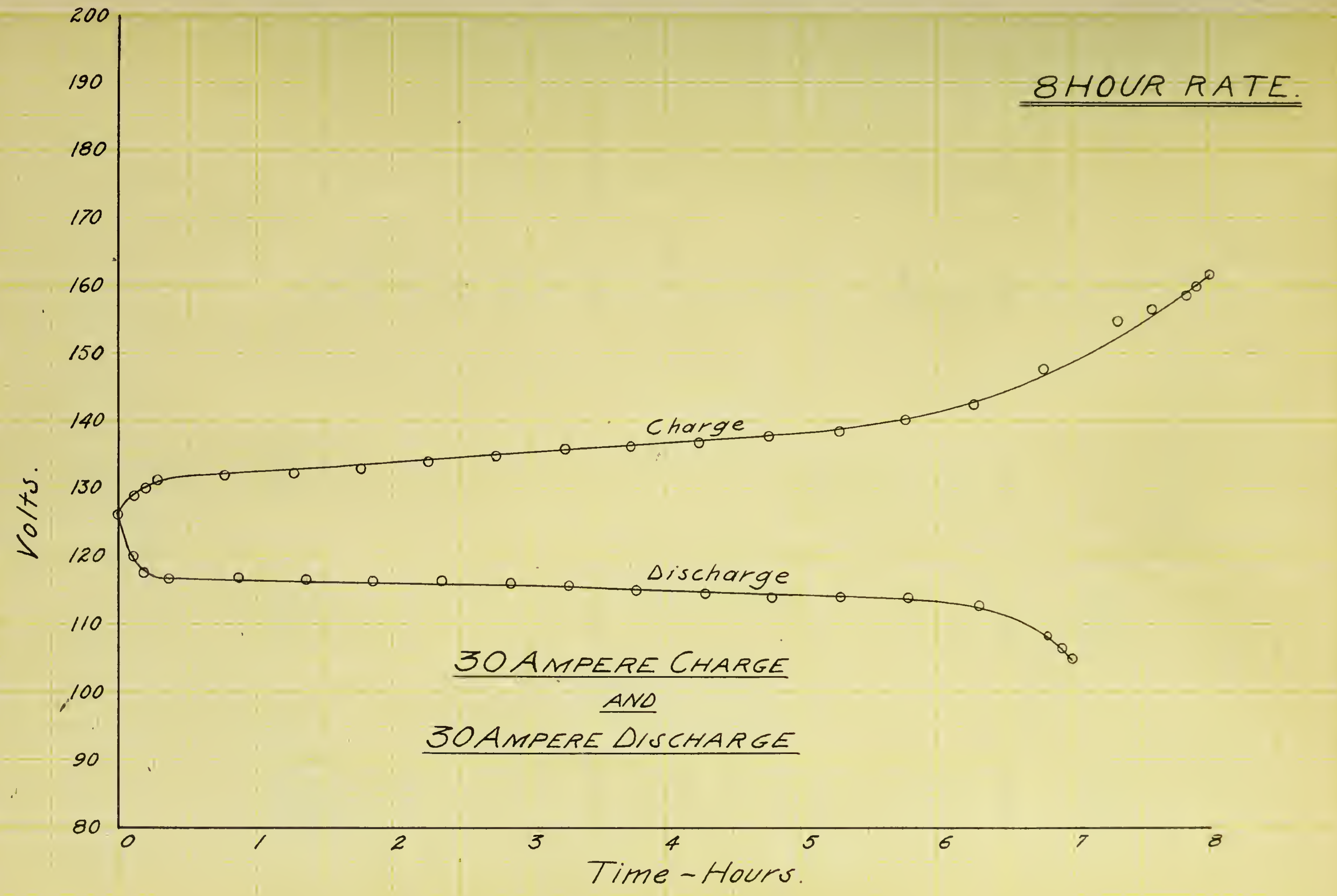
Time	E	Amperes	Hours	Ampere Hours	Watt Hours
Carried over				239.7	32634
10.42	126	30			
.45	129	"	.05	1.5	133
.50	130	"	.083	2.5	325
11.00	131	"	.160	4.8	590
.30	132	"	.5	15	1980
12.00	132.5	"	.5	15	1990
.30	133	"	.5	15	2000
1.00	134	"	.5	15	2008
.30	135	"	.5	15	2020
2.00	136	"	.5	15	2040
.30	136.5	"	.5	15	2050
3.00	137	"	.5	15	2060
.30	138	"	.5	15	2070
4.00	138.7	"	.5	15	2080
.30	140.5	"	.5	15	2110
5.00	142.5	"	.5	15	2140
.30	148	"	.5	15	2220
6.00	155	"	.5	15	2330
.15	157	"	.25	7.5	1180
.30	159	"	.25	7.5	1190
.35	160	"	.083	2.5	400
.40	162	"	.083	2.5	405
7.58			7.965		
		Total		478.5	66020

8 HOUR DISCHARGE #1.

	E	I	Hours	Ampere Hours	Watt Hours
11.30	127	30			
.33	122.5	"	.05	1.5	184
.35	117.6	"	.033	.9	106
.45	117	"	.166	4.8	505
12.00	116	"	.25	7.5	870
12.30	116	"	.5	15	1740
1.00	115.2	"	.5	15	1725
.30	115	"	.5	15	1720
2.00	114.7	"	.5	15	1715
.30	114	"	.5	15	1710
3.00	113.5	"	.5	15	1700
.30	113.5	"	.5	15	1700
4.00	113.5	"	.5	15	1700
.30	113	"	.5	15	1695
5.00	112.5	"	.5	15	1685
.30	112	"	.5	15	1680
6.00	109.5	"	.5	15	1640
.15	109	"	.25	7.5	825
.30	105	"	.25	7.5	790
.35	104.5	"	.083	2.5	785
			7.082	212.2	26470

8 HOUR DISCHARGE #2.

	E	I	Hours	Ampere Hours	Watts Hours
Carried over				212.2	26470
3.40	128	30			
.43	126	"	.05	1.5	188
.46	120	"	.05	1.5	180
.50	117.5	"	.067	2.	235
4.00	117	"	.166	4.8	570
4.30	117	"	.5	15	1765
5.00	116.5	"	.5	15	1750
.30	116.2	"	.5	15	1745
6.00	116	"	.5	15	1740
.30	116	"	.5	15	1740
7.00	115.5	"	.5	15	1730
.30	115	"	.5	15	1720
8.00	114.6	"	.5	15	1715
.30	114	"	.5	15	1710
9.00	113.9	"	.5	15	1710
.30	113.3	"	.5	15	1700
10.00	110.5	"	.5	15	1650
.30	108.4	"	.5	15	1630
.35	106.7	"	.083	2.5	265
.40	105	"	.083	2.5	260
700			7.00	209.8	24103
	Total			422	50513
	Ampere Hour Efficiency				87.5%
	Watt Hour Efficiency				76.5%


8 HOUR RATE.
Volts.
200
190
180
170
160
150
140
130
120
110
100
90
80
0
1
2
3
4
5
6
7
8
Time - Hours.
Charge
Discharge
30 AMPERE CHARGE
AND
30 AMPERE DISCHARGE

5 HOUR CHARGE #1.

Time	E	I	Hours	Ampere Hours	Watt Hours
1.00	125	30			
.03	130	"	.05	1.5	195
.05	131	"	.033	.98	128
.10	134	"	.083	2.5	335
.20	134.5	"	.167	5.	673
.30	134.7	"	.167	5.	676
8.00	135	"	.5	15	2025
.30	136	"	.5	15	2040
9.00	137	"	.5	15	2055
.30	140	"	.5	15	2100
10.00	141	"	.5	15	2114
.30	142	"	.5	15	2130
11.00	143	"	.5	15	2147
.30	145	"	.5	15	2174
12.00	153	"	.5	15	2195
.30	160	"	.5	15	2400
1.00	165	"	.5	15	2480
			6.000	179.98	25867

5 HOUR CHARGE #2.

		I	Hours	Ampere Hours	Watt Hours
Brought forward				179.98	25867
5.30	126	30			
.33	129	"	.05	1.5	144
.35	133	"	.033	.99	131
.40	134	"	.083	2.5	335
6.00	134.2	"	.33	9.9	1330
.30	134.6	"	.5	15	2020
7.00	135.3	"	.5	15	2036
.30	135.8	"	.5	15	2040
8.00	135.9	"	.5	15	2040
.30	136.4	"	.5	15	2050
9.00	140	"	.5	15	2100
.30	143	"	.5	15	2140
10.00	144	"	.5	15	2160
.30	145	"	.5	15	2180
11.00	146.2	"	.5	15	2190
.20	152	"	.33	9.9	1505
.30	153	"	.166	5.	790
.40	163	"	.166	5.	815
			6.158	184.79	26056
	Total			364.68	51923

5 HOUR DISCHARGE #1.

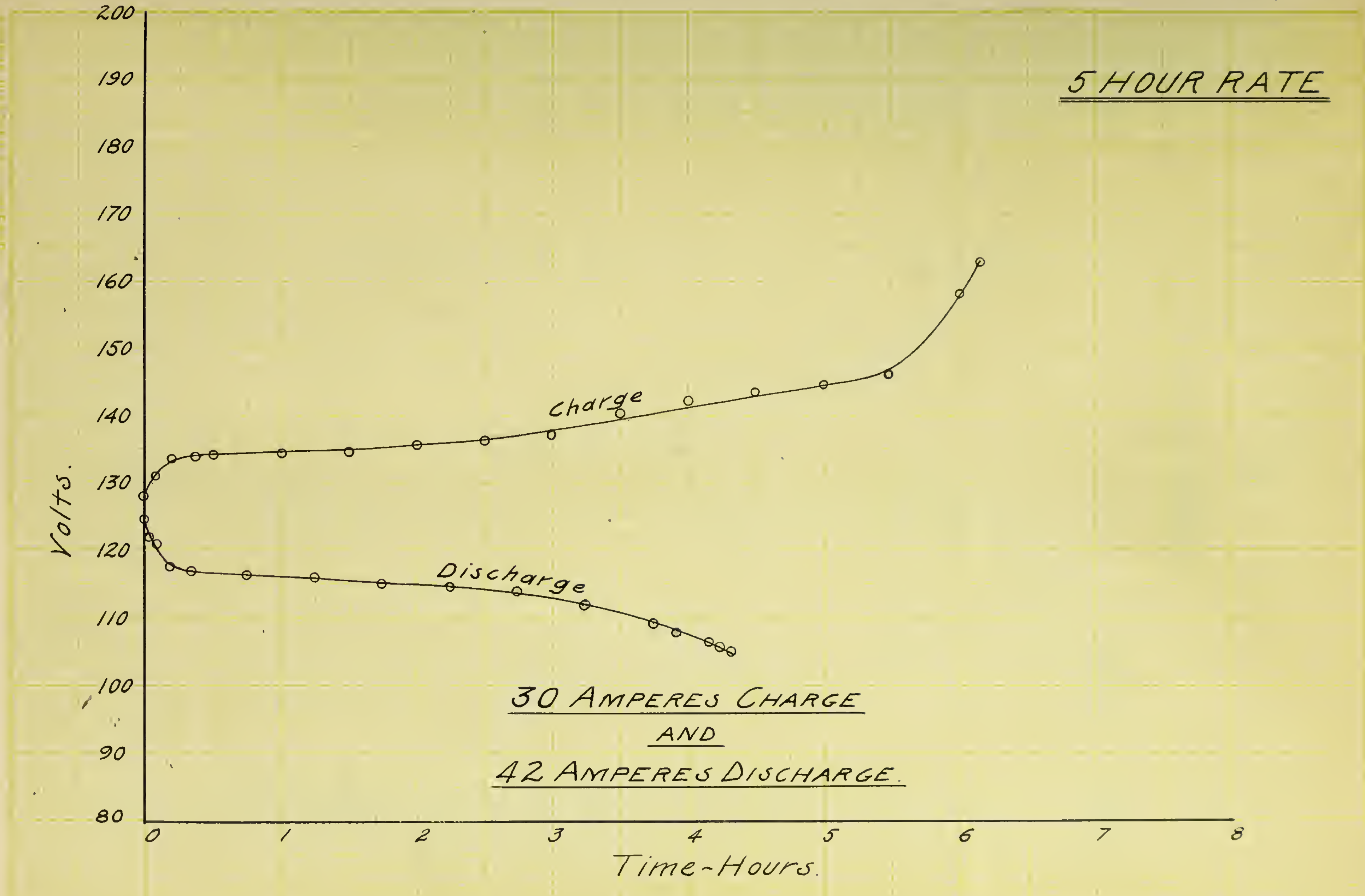
Time	E	I	Hours	Ampere Hours	Watt Hours
3.10	128	42			
.13	116	"	.05	2.1	243.5
.15	116	"	.033	1.4	162
.20	115	"	.083	3.48	400
.25	114.8	"	.083	3.48	399
.30	113.5	"	.083	3.48	935
4.00	113	"	.5	21.	2373
.30	112.8	"	.5	21	2365
5.00	112	"	.5	21	2350
.30	111.3	"	.5	21	2340
6.00	111	"	.5	21	2330
.30	110.1	"	.5	21	2314
.40	107	"	.167	7	750
.50	104	"	.167	7	728
			3.666	153.94	17689

5 HOUR DISCHARGE #2.

Time	E	I	Hours	Ampere Hours	Watt Hours
Brought forward				153.94	17689
1.10	128	42			
.13	122	"	.05	2.1	256
.15	121	"	.033	1.4	170
.20	117.5	"	.083	3.5	410
.30	117	"	.166	7.	820
2.00	116.2	"	.5	21	2440
.30	116	"	.5	21	2440
3.00	115	"	.5	21	2420
.30	114.5	"	.5	21	2400
4.00	114	"	.5	21	2390
.30	112.5	"	.5	21	2380
.40	112	"	.166	7	785
.50	110	"	.166	7	770
5.00	108.7	"	.166	7	760
.10	108	"	.166	7	750
.20	106.5	"	.166	7	745
.25	105.7	"	.083	3.5	370
.30	105	"	.083	3.5	368
4.33			4328	182.0	20674
	Total			335.94	38363

Ampere Hour Efficiency = 92%

Watt Hour Efficiency = 74%



5 HOUR RATE
200
190
180
170
160
150
140
130
120
110
100
90
80
Volts.
Charge
Discharge
30 AMPERES CHARGE
AND
42 AMPERES DISCHARGE.
0
1
2
3
4
5
6
7
8
Time-Hours.

3 HOUR CHARGE #1.

Time	E	I	Hours	Ampere Hours	Watt Hours
2.25	131	30			
.28	132	"	.15	1.5	198
.30	134	"	.033	.98	131
.35	135	"	.083	2.5	339
.45	135.8	"	.167	5.	680
3.00	136	"	.25	7.5	1020
.30	138.5	"	.5	15	2080
4.00	140	"	.5	15	2100
.30	141	"	.5	15	2117
5.00	142	"	.5	15	2130
.30	142.5	"	.5	15	2140
6.00	143	"	.5	15	2145
.30	144.2	"	.5	15	2165
7.00	145	"	.5	15	2175
.30	149	"	.5	15	2240
.45	158	"	.25	7.5	1185
8.00	165	"	.25	7.5	1240
			5.583	167.48	24085

3 HOUR CHARGE #2.

Time	E	I	Hours	Ampere Hours	Watt Hours
Brought forward				167.48	24085
10.40	130.8	30			
.43	132	"	.05	1.5	198
.45	133.9	"	.033	.98	131
.50	135.3	"	.083	2.5	338
11.00	136	"	.167	5.	680
.30	137	"	.5	15	2055
12.00	138	"	.5	15	2070
.30	139.5	"	.5	15	2095
1.00	140	"	.5	15	2100
.30	141	"	.5	15	2115
2.00	142	"	.5	15	2130
.30	142.5	"	.5	15	2140
3.00	142.8	"	.5	15	2145
.30	143	"	.5	15	2148
.45	145	"	.25	7.5	1090
4.00	155	"	.25	7.5	1160
.05	160	"	.083	2.5	400
.10	164	"	.083	2.5	410
			5.500		
	Total			334.46	47489

3 HOUR DISCHARGE #1.

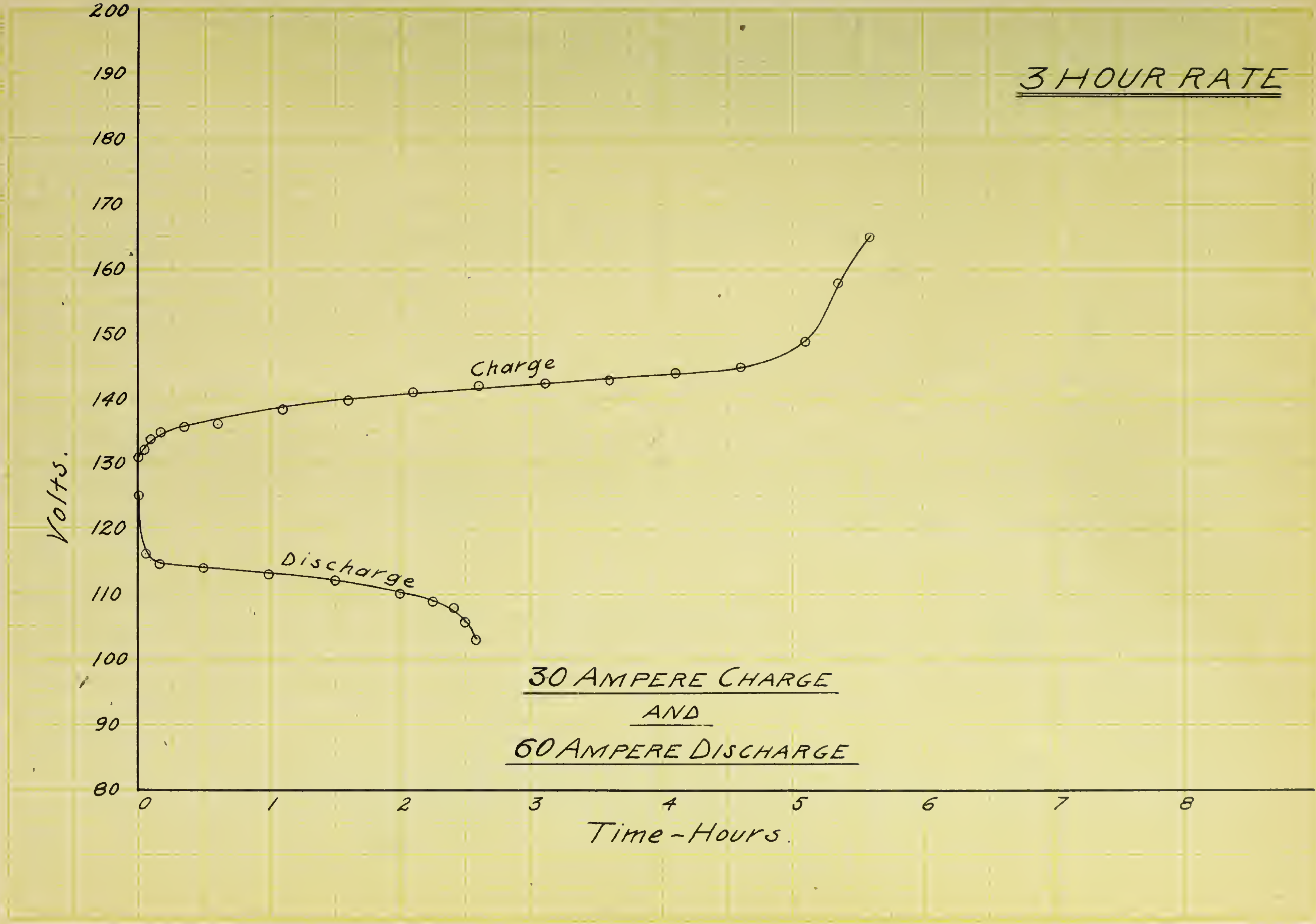
Time	E	I	Hours	Ampere Hours	Watt Hours
11.40	120	60			
.43	117	"	.05	3.	351
.45	114.5	"	.033	1.98	227
.50	114	"	.083	5.	570
12.00	113.3	"	.167	10.	1133
.30	113.1	"	.5	30	3400
1.00	113	"	.5	30	3390
.30	111	"	.5	30	3330
.40	110.6	"	.167	10	1106
.50	110	"	.167	10	1100
2.00	108	"	.167	10	1080
.10	106	"	.167	10	1060
.20	103	"	.167	10	1030
			2.668	159.98	17777

3 HOUR DISCHARGE #2.

Time	E	I	Hours	Ampere Hours	Watt Hours
Brought forward				159.98	17777
8.00	125	60			
.03	116	"	.05	3.	348
.05	115	"	.033	1.98	228
.10	114.8	"	.083	5.	574
.30	114	"	.333	20.	2280
9.00	113	"	.5	30.	3390
.30	112	"	.5	30.	3360
10.00	110	"	.5	30	3300
.15	109	"	.25	15	1635
.25	108	"	.167	10	1080
.30	105.9	"	.083	5	530
.35	103.1	"	.083	5	516
			2.582		
		Total		314.96	35018

Ampere Hour Efficiency = 93.8%

Watt Hour Efficiency = 74 %


3 HOUR RATE
Charge
Discharge
30 AMPERE CHARGE
AND
60 AMPERE DISCHARGE
Volts.
Time-Hours.
200
190
180
170
160
150
140
130
120
110
100
90
80
0
1
2
3
4
5
6
7
8

120 HOUR RATE CHARGE #1.

Time	E	I	Hours	Ampere Hours	Watt Hours
4.58	128	30			
5.00	130	"	.033	.99	130
5.05	131	"	.083	2.5	326
5.10	132	"	.083	2.5	327
5.30	133	"	.33	9.9	1320
6.00	134	"	.5	15	2000
6.30	135.2	"	.5	15	2080
7.00	136.2	"	.5	15	2050
7.30	136.3	"	.5	15	2050
8.00	144	"	.5	15	2150
8.30	159.1	"	.5	15	2380
8.50	160	"	.33	9.9	1590
			3.859	114.79	16403

120 HOUR RATE CHARGE #2.

Time	E	I	Hours	Ampere Hours	Watt Hours
Brought forward				114.79	16403
10.00	127	30			
10.05	130	"	.083	2.5	324
10.10	132	"	.083	2.5	327
10.30	132	"	.33	9.9	1320
11.00	133.5	"	.5	15	1980
11.30	134.6	"	.5	15	2015
12.00	136	"	.5	15	2050
12.30	137	"	.5	15	2060
1.00	140	"	.5	15	2100
1.30	157	"	.5	15	2360
1.40	159	"	.166	5	790
1.50	160	"	.166	5	800
3.82			3.828		
	Total			229.6	32524

120 AMPERE DISCHARGE #1.

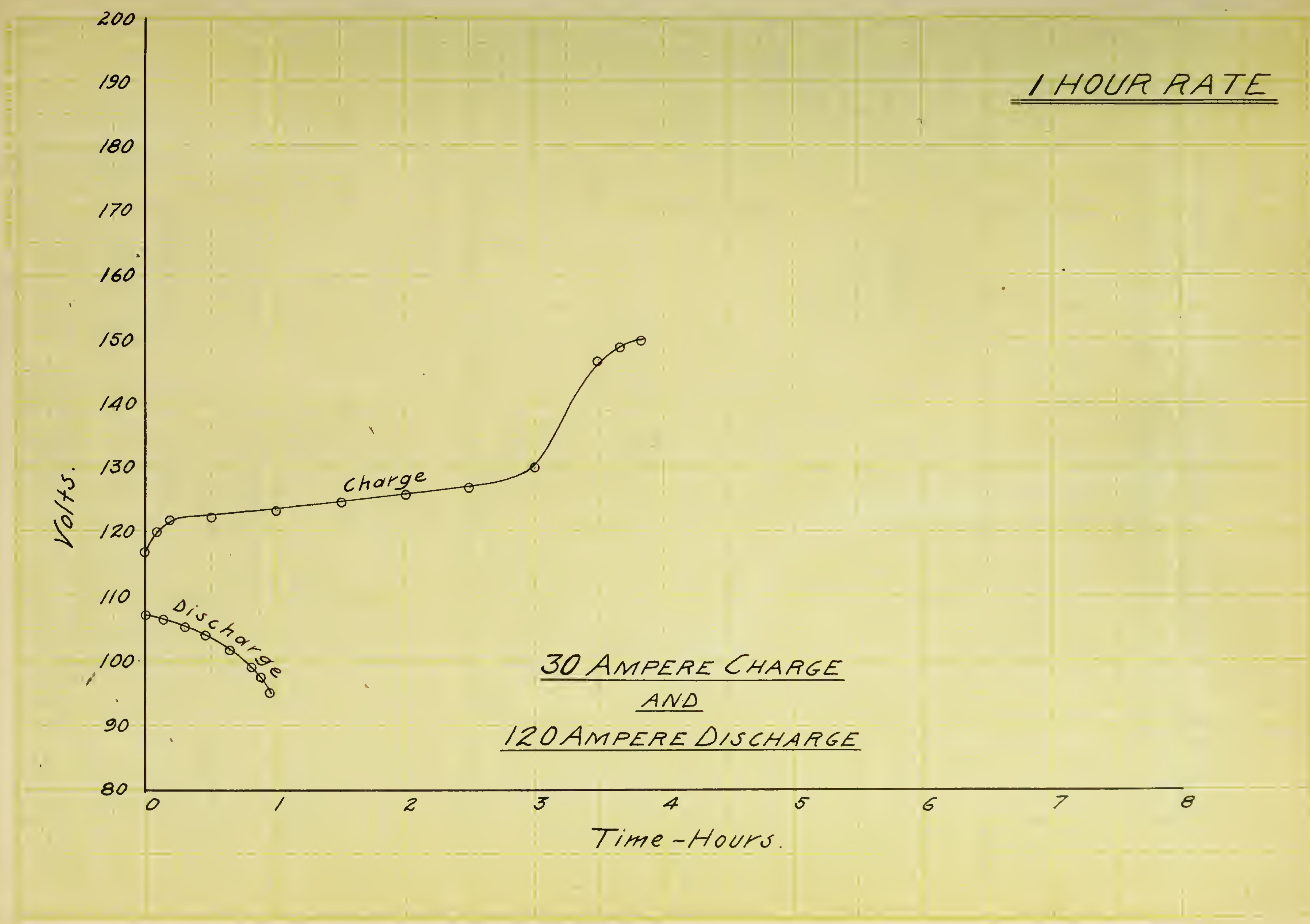
Time	E	I	Hours	Ampere Hours	Watt Hours
4.00	107	120			
4.03	106.5	"	.05	6	640
4.05	106.5	"	.033	4	423
4.10	106	"	.083	10	1060
4.15	105.5	"	.083	10	1060
4.20	105	"	.083	10	1048
4.25	104	"	.083	10	1040
4.30	103	"	.083	10	1025
4.35	102	"	.083	10	1018
4.40	101	"	.083	10	1005
4.45	100	"	.083	10	1000
4.50	97	"	.083	10	894
			.830	100	10213

120 AMPERE DISCHARGE #2.

Time	E	I	Hours	Ampere Hours	Watt Hours
Brought forward				100	10213
857	107	120			
900	106.5		.05	6	640
905	106.5		.083	10	1050
910	106		.083	10	1060
915	105		.083	10	1048
920	105		.083	10	1048
925	104		.083	10	1040
930	103		.083	10	1025
935	101.5		.083	10	1015
940	101		.083	10	1010
945	99		.083	10	990
950	97.5		.083	10	968
955	95		.083	10	945
			.963	116	11829
		Total		216	22060

Ampere Hour Efficiency = 95%

Ampere Hour Efficiency = 69%


1 HOUR RATE
30 AMPERE CHARGE
AND
120 AMPERE DISCHARGE
Charge
Discharge
Volts.
Time - Hours.
200
190
180
170
160
150
140
130
120
110
100
90
80
0
1
2
3
4
5
6
7
8

CADMIUM READINGS DURING CHARGE AND DISCHARGE.

In taking cadmium readings either on charge or discharge it is necessary that the normal charge or discharge for that rate current be flowing. On discharge, the cadmium is positive and negative elements, in a voltaic sense, and hence the cell voltage is equal to the difference between the voltage from the cadmium to positive plate and the voltage from the cadmium to negative plate. On charge, the cell voltage is equal to the difference of the cadmium readings, until the cell voltage reaches 2.35-2.4 volts, when the sponge lead element or negative has charged so that it is no longer negative to the cadmium but positive to it. Hence after the cell voltage reaches the above value, the cell voltage is equal to the sum of the cadmium readings. At the time that the reading of voltage between cadmium and the negative element is passing through zero, the cell voltage is given at once by the reading between the cadmium and the positive plate.

The cadmium readings were found in almost every case, to check closely with the terminal voltage of the cells, although owing to the small readings from cadmium to the negative plate, there were some slight discrepancies.

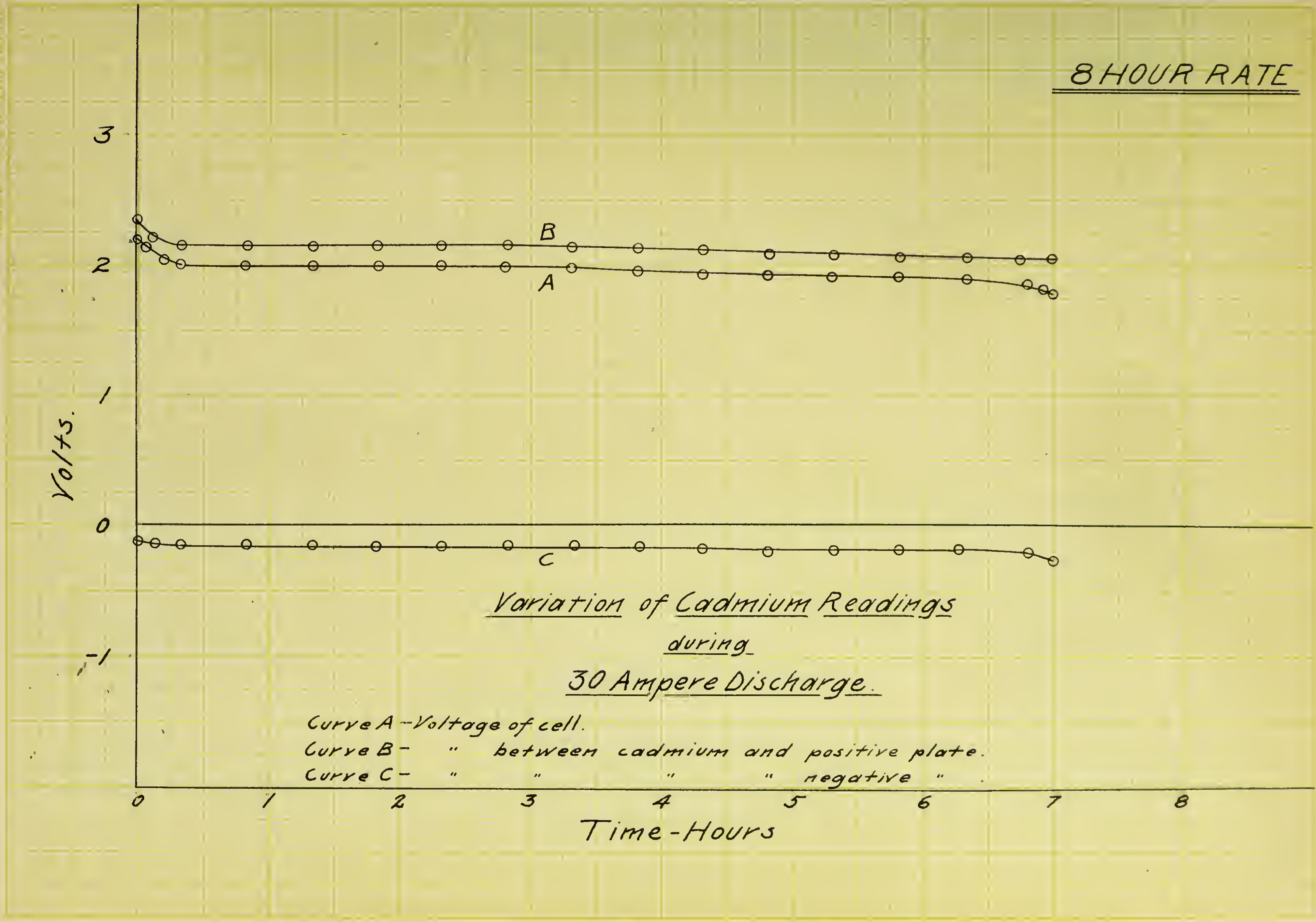
The readings were taken more frequently on approaching the end of charge or discharge, as it was then that the voltage changed most rapidly.

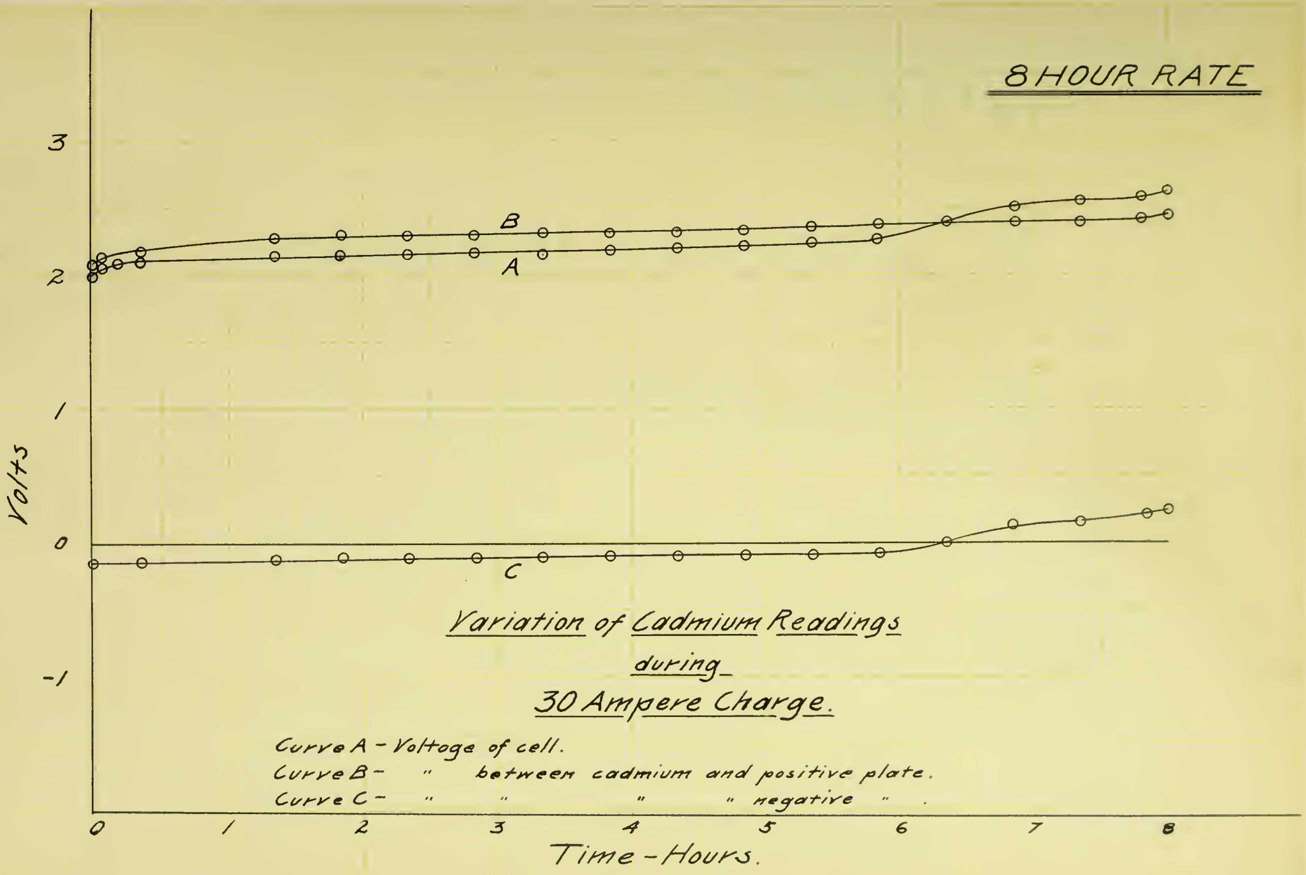
8 HOUR CHARGE CADMIUM READINGS.

Time	Cad. to +	Cad. to −	+ to −
6.40	2.13	−.16	2.
.43	2.14	−.13	2.03
.45	2.2	−.13	2.08
.50	2.23	−.13	2.1
7.00	2.24	−.13	2.12
.15	2.24	−.13	2.12
.45	2.26	−.13	2.13
8.00	2.28	−.123	2.16
.30	2.3	−.12	2.17
9.00	2.3	−.116	2.17
.30	2.303	−.116	2.175
10.00	2.31	−.11	2.18
.30	2.316	−.103	2.21
11.00	2.316	−.103	2.21
.30	2.32	−.1	2.22
12.00	2.36	−.09	2.28
.30	2.37	−.067	2.3
1.00	2.4	.0	2.4
.30	2.4	+.12	2.5
2.00	2.4	+.18	2.55
.30	2.42	+.2	2.6
.35	2.44	+.2	2.64
.40	2.46	+.21	2.66

8 HOUR DISCHARGE CADMIUM READINGS.

Time	Cad. to +	Cad. to −	+ to −
3.40	2.33	.13	2.2
.43	2.3	.133	2.163
.46	2.2	.133	2.033
.50	2.167	.15	2.
4.00	2.16	.15	2.
.30	2.16	.15	2.
5.00	2.16	.15	2.
.30	2.16	.15	2.
6.00	2.16	.15	2.
.30	2.16	.15	2.
7.00	2.154	.162	1.99
.30	2.13	.164	1.97
8.00	2.13	.166	1.94
.30	2.1	.166	1.94
9.00	2.1	.17	1.93
.30	2.09	.18	1.92
10.00	2.06	.183	1.9
.30	2.06	.2	1.87
.35	2.05	.25	1.83
.40	2.05	.26	1.8


8 HOUR RATE
Volts.
3
2
1
0
-1
B
A
C
Variation of Cadmium Readings
during
30 Ampere Discharge.
Curve A - Voltage of cell.
Curve B - " between cadmium and positive plate.
Curve C - " " " " negative " .
0
1
2
3
4
5
6
7
8
Time-Hours

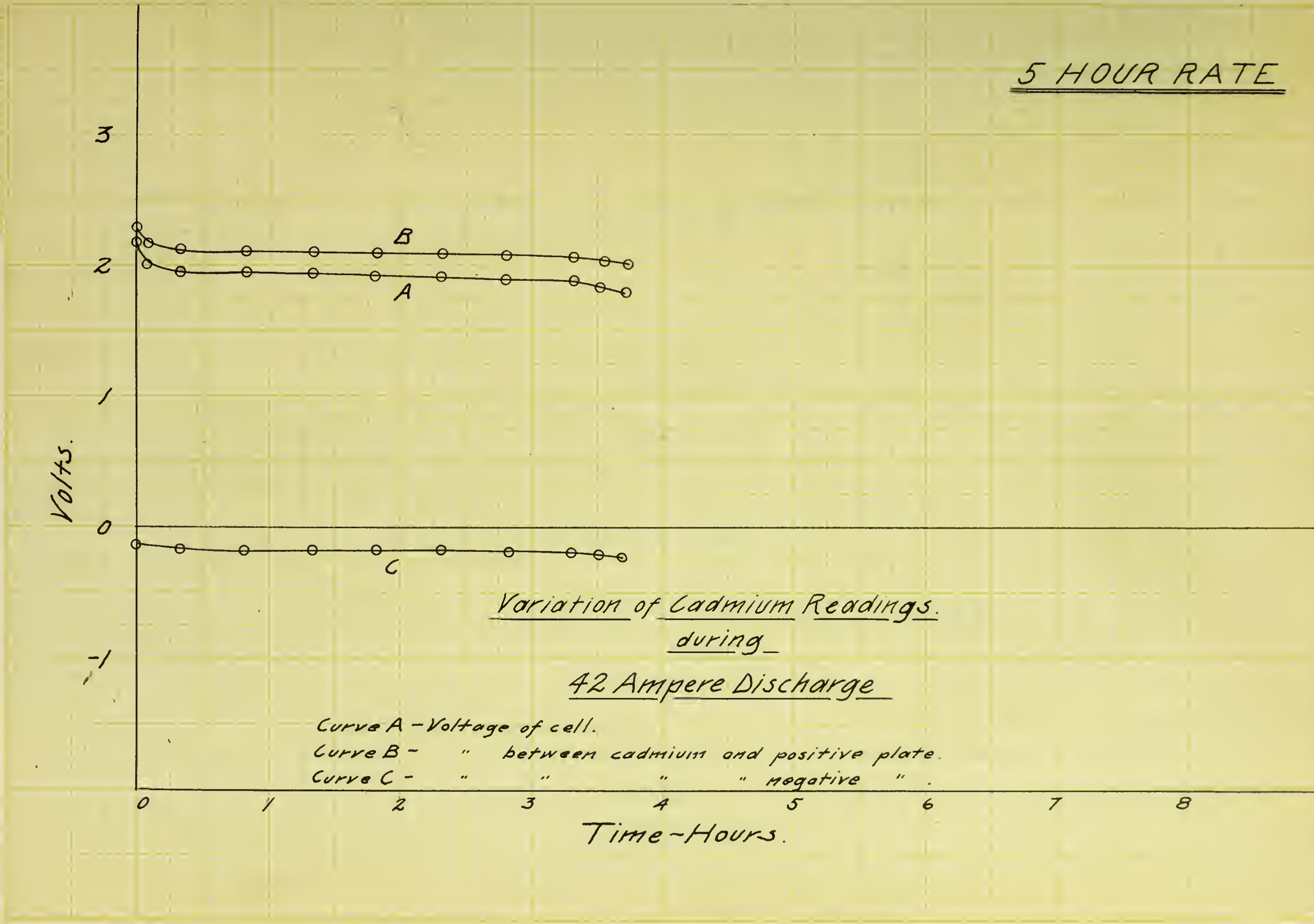

8 HOUR RATE
3
2
1
0
-1
Volts
B
A
C
Variation of Cadmium Readings
during
30 Ampere Charge.
Curve A - Voltage of cell.
Curve B - " between cadmium and positive plate.
Curve C - " " " " negative " .
0
1
2
3
4
5
6
7
8
Time - Hours.

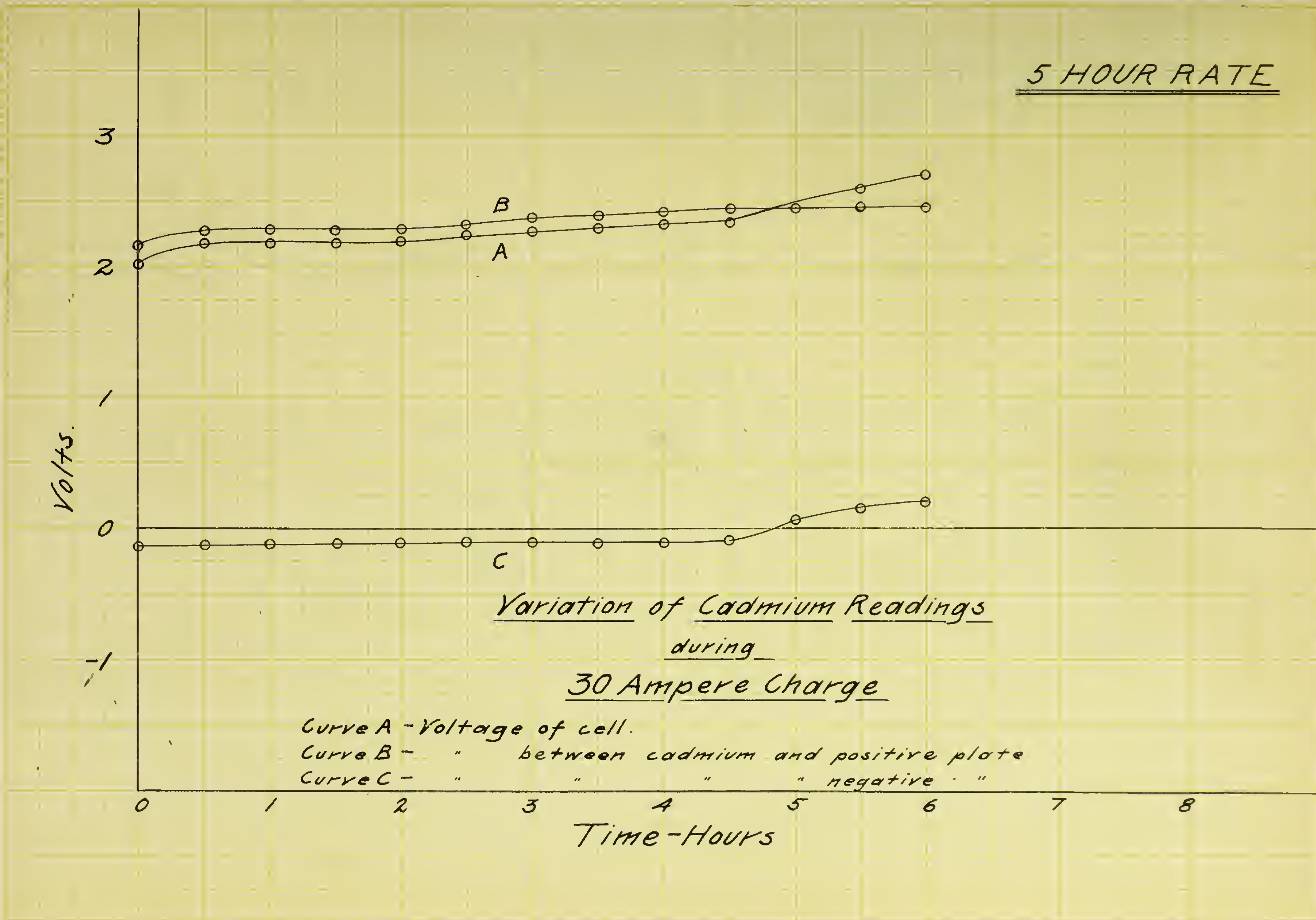
5 HOUR CHARGE CADMIUM READINGS.

Time	Cad. to +	Cad. to −	+ to .
7.00	2.16	.13	2.03
.03	2.2	.13	2.1
.05	2.23	.13	2.1
.10	2.26	.12	2.16
.20	2.26	.11	2.16
.30	2.26	.11	2.17
8.00	2.26	.11	2.17
.30	2.26	.11	2.17
9.00	2.28	.10	2.2
.30	2.32	.10	2.26
10.00	2.4	.10	2.28
.30	2.4	-.10	2.3
11.00	2.43	-.09	2.33
.30	2.45	+.08	2.35
12.00	2.45	+.06	2.5
.30	2.46	.16	2.6
1.00	2.46	.21	2.35

5 HOUR DISCHARGE CADMIUM READINGS.

Time	Cad. to +	Cad. to −	+ to −
3.10	2.3	.11	2.2
.11	2.2	.12	2.1
.12	2.17	.16	2.
.13	2.16	.16	2.
.15	2.16	.16	2.
.20	2.15	.16	1.98
.25	2.14	.16	1.98
.30	2 .14	.16	1.97
4.00	2.12	.17	1.96
.30	2.11	.17	1.96
5.00	2.1	.17	1.94
.30	2.1	.17	1.93
6.00	2.09	.18	1.91
.30	2.07	.18	1.9
.40	2.04	.20	1.83
.50	2.01	.21	1.8


5 HOUR RATE
3
2
1
0
-1
Volts.
B
A
C
Variation of Cadmium Readings.
during
42 Ampere Discharge
Curve A - Voltage of cell.
Curve B - " between cadmium and positive plate.
Curve C - " " " " negative " .
0
1
2
3
4
5
6
7
8
Time-Hours.

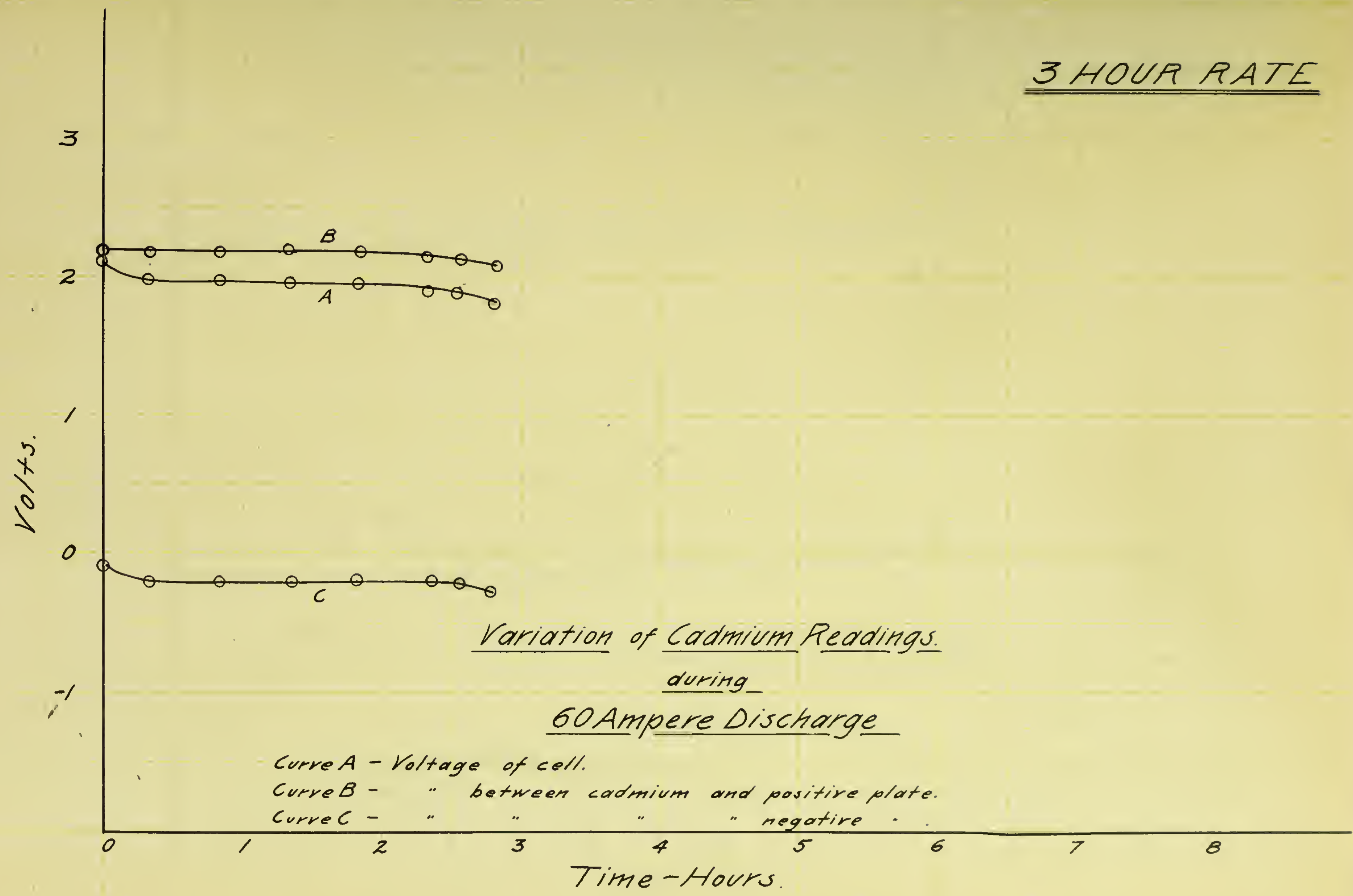

5 HOUR RATE
Volts.
3
2
1
0
-1
B
A
C
Variation of Cadmium Readings
during
30 Ampere Charge
Curve A - Voltage of cell.
Curve B - " between cadmium and positive plate
Curve C - " " " " negative "
0
1
2
3
4
5
6
7
8
Time-Hours

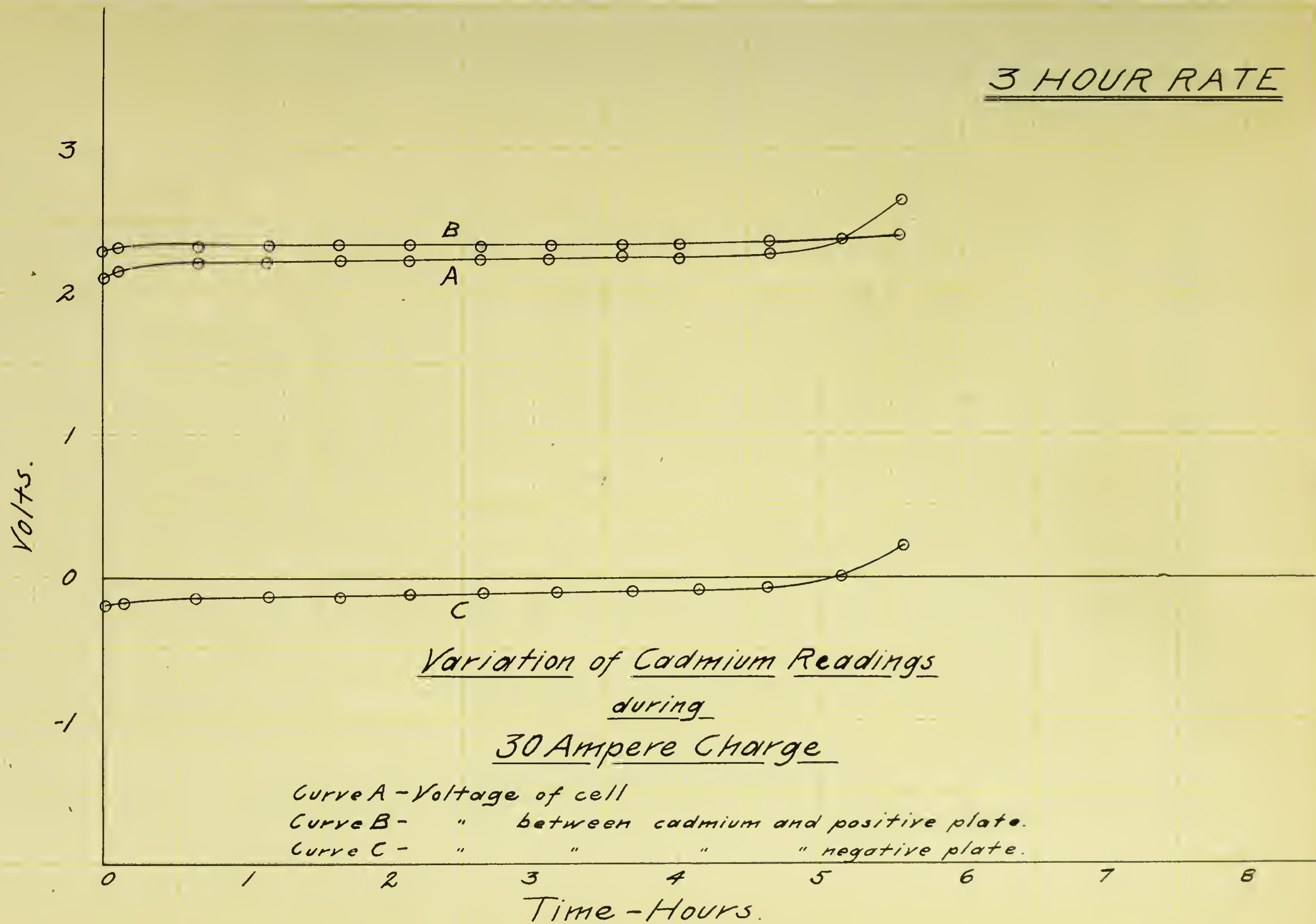
3 HOUR CHARGE CADMIUM READINGS.

Time	Cad. to +	Cad. to -	+ to -
2.25	2.3	.2	2.1
.28	2.3	.2	2.11
.30	2.3	.18	2.13
.35	2.3	.15	2.15
.45	2.31	.15	2.15
3.00	2.31	.14	2.2
.30	2.32	.13	2.2
4.00	2.32	.12	2.23
.30	2.32	.11	2.24
5.00	2.33	.11	2.24
.30	2.33	.10	2.24
6.00	2.33	.10	2.245
.30	2.34	.09	2.25
7.00	2.36	.08	2.28
.30	2.38	0	2.38
.45	2.39	.03	2.42
8.00	2.4	.24	2.64

3 HOUR DISCHARGE CADMIUM READINGS.

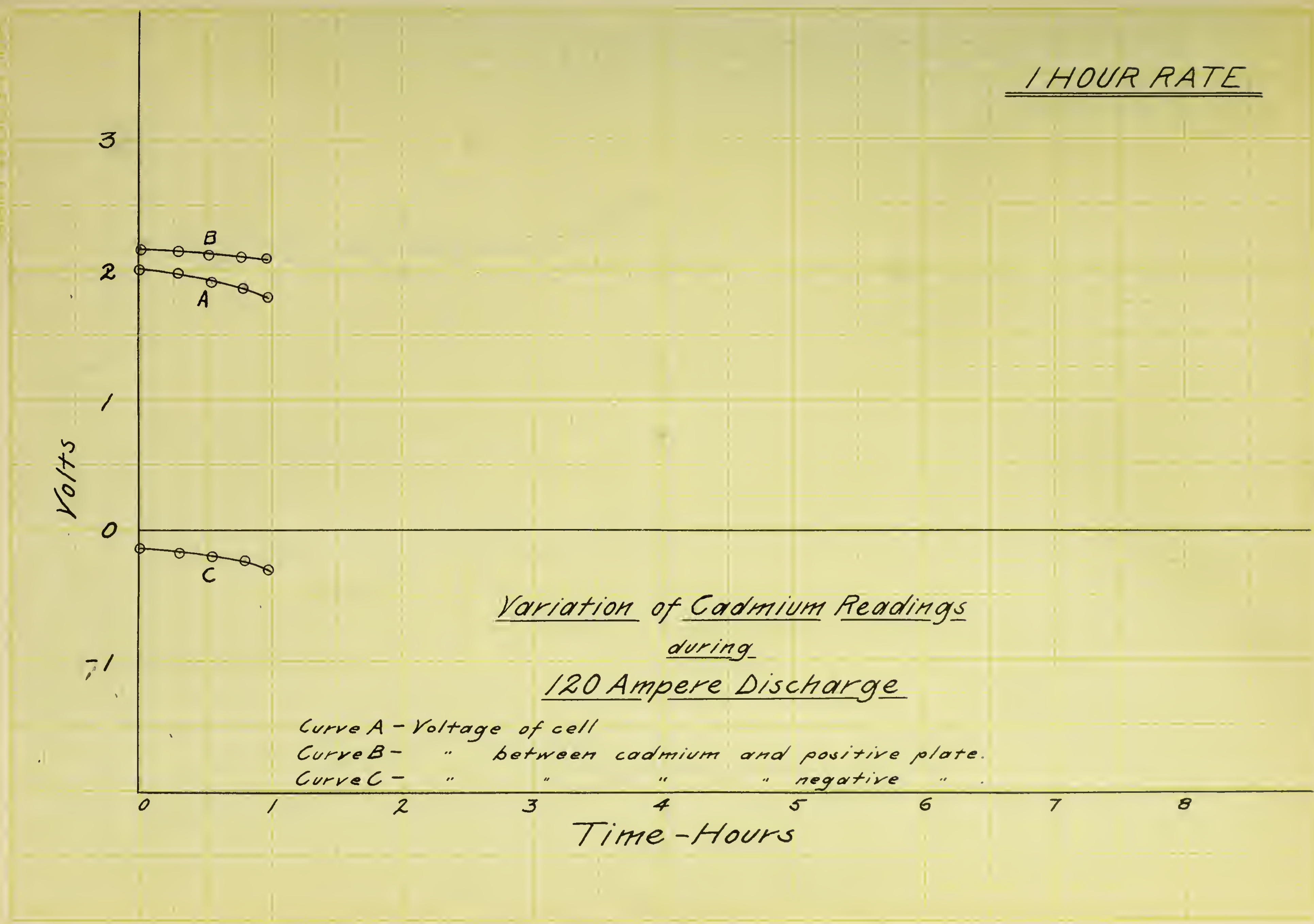
Time	Cad. to +	Cad. to -	+ to -
11.40	2.18	.1	2.1
.43	2.18	.14	2.05
.45	2.18	.18	2.
.50	2.18	.18	2.
12.00	2.18	.2	1.98
.30	2.18	.2	1.98
1.00	2.18	.2	1.97
.30	2.17	.205	1.96
.40	2.165	.205	1.96
.50	2.16	.209	1.95
2.00	2.14	.21	1.9
.10	2.11	.22	1.88
.20	2.09	.28	1.81

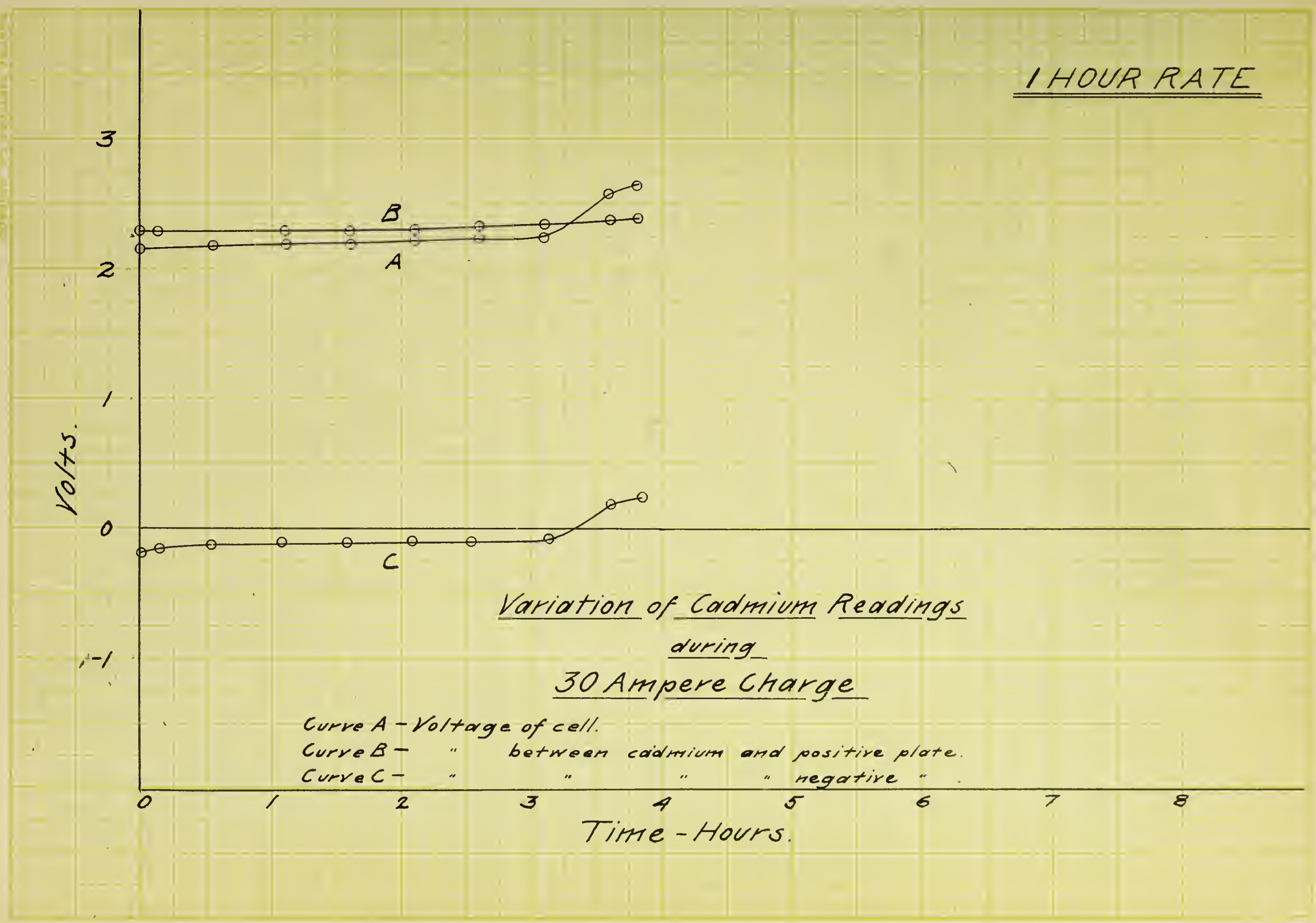

3 HOUR RATE
Variation of Cadmium Readings
during
60 Ampere Discharge
Curve A - Voltage of cell.
Curve B - " between cadmium and positive plate.
Curve C - " " " " negative "
Volts.
Time - Hours.
A
B
C
3
2
1
0
-1
0
1
2
3
4
5
6
7
8


3 HOUR RATE
Volts.
3
2
1
0
-1
B
A
C
Variation of Cadmium Readings
during
30 Ampere Charge
Curve A - Voltage of cell
Curve B - " between cadmium and positive plate.
Curve C - " " " " negative plate.
0
1
2
3
4
5
6
7
8
Time - Hours.

1 HOUR CHARGE AND DISCHARGE CADMIUM READINGS.

	Time	Cad. to +	Cad. to −	+ to −
	4.58	2.3	-.18	2.15
	5.00	2.3	-.18	2.16
	.05	2.3	-.15	2.18
	.10	2.3	-.12	2.2
	.30	2.3	-.12	2.2
	6.00	2.3	-.12	2.2
Charge	.30	2.3	-.11	2.22
	7.00	2.34	-.11	2.25
	.30	2.35	-.10	2.25
	8.00	2.4	-.07	2.36
	.30	2.4	+.2	2.6
	.50	2.4	+.22	2.65
	8.57	2.15	.14	2.
	9.00	2.15	.15	2.
	.05	2.15	.15	2.
	.10	2.15	.15	1.99
Discharge	.15	2.15	.18	1.98
	.20	2.15	.18	1.96
	.25	2.13	.18	1.93
	.30	2.1	.2	1.9
	.35	2.1	.2	1.89
	.40	2.1	.2	1.88
	.45	2.1	.23	1.87
	.50	2.1	.24	1.82
	.55	2.1	.3	1.8


1 HOUR RATE
Volts
3
2
1
0
-1
B
A
C
Variation of Cadmium Readings
during
120 Ampere Discharge
Curve A - Voltage of cell
Curve B - " between cadmium and positive plate.
Curve C - " " " " negative " .
0
1
2
3
4
5
6
7
8
Time - Hours

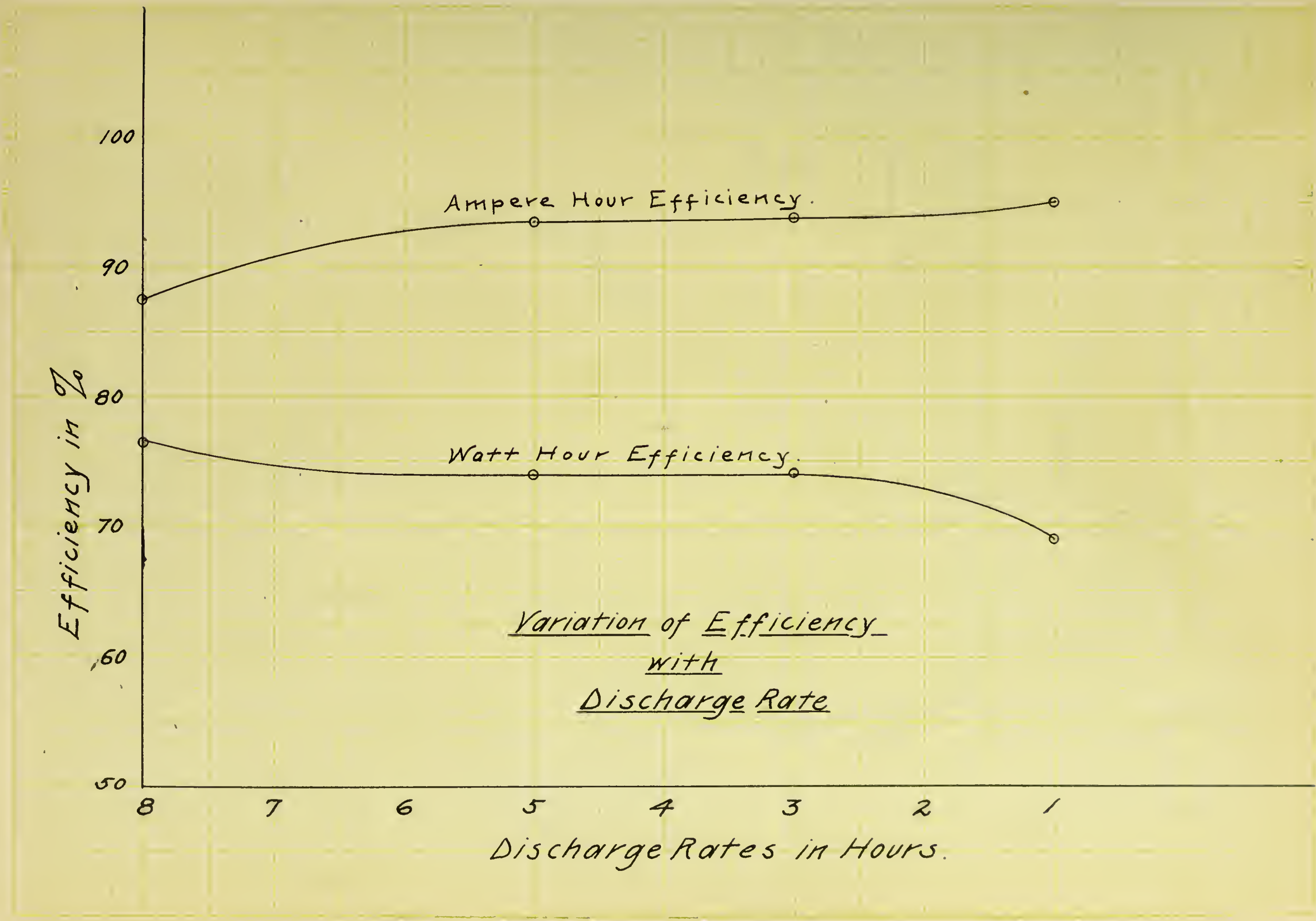

1 HOUR RATE
Volts.
3
2
1
0
-1
B
A
C
Variation of Cadmium Readings
during
30 Ampere Charge
Curve A - Voltage of cell.
Curve B - " between cadmium and positive plate.
Curve C - " " " " negative " .
0
1
2
3
4
5
6
7
8
Time - Hours.

EFFICIENCY OF THE EFFICIENCIES.

In figuring efficiencies, the total input of the battery for two charges was divided by the total output for two discharges, thus giving a more accurate value, than if only one cycle was used. As before mentioned, the cells were charged each time with a current of 30 amperes, irrespective of the discharge rate. Both ampere hour and watt hour efficiencies were obtained. With discharge rates above normal, the watt hour efficiency decreased inversely with the discharge rate, but the ampere hour efficiency increased as the discharge rate was increased. This increase in ampere hour efficiency is due to the fact that after a rapid discharge, the cells are not completely exhausted, even though their voltage may have reached 1.8 volts and hence it does not require the full 8 hours to recharge at normal rate. By thus discharging at a rapid rate, a battery even if in poor condition, may show a very high ampere hour efficiency, hence, the ampere hour efficiency is of little value in indicating the true condition of a battery.

The watt hour efficiency, on the other hand, is the real indication of the usefulness of a battery and conveys a definite idea of the energy efficiency. The main reason for the lower watt hour efficiencies at discharge rates above normal, is the fact that more energy is used in overcoming the internal resistance of the battery, in gassing and in heating. Also, on rapid discharge, polarization is increased, thus reducing the battery voltage.

The loss of pressure and consequently, loss of efficiency at high rates of discharge is well shown by the voltage curves. The lower the rate of discharge the closer the curves of charge and discharge approach and, since the difference between the two curves represents the pressure loss, the efficiency is evidently higher for lower rates of discharge.


Ampere Hour Efficiency.
Watt Hour Efficiency.
Variation of Efficiency
with
Discharge Rate
Efficiency in %
100
90
80
70
60
50
8
7
6
5
4
3
2
1
Discharge Rates in Hours.

EFFICIENCIES.

Rate	Watt Hour	Ampere Hour
8 hour	76.5	87.5
5 hour	74	93.5
3 hour	74	93.8
1 hour	69	95

INTERNAL RESISTANCE.

In the test of the internal resistance of the Gould battery, an effort was made to obtain an approximate value, simply, of the causes which produce drop across the terminals of the cells. This drop is caused, not only by the ohmic resistance, but also by the effects of polarization and counter E.M.F. This resistance has been named by Mr. Camar Lyndon, "Virtual Resistance."

The ohmic internal resistance of a cell or battery varies at different periods of charge and discharge, owing to the differing degrees of dilution of electrolyte and sulphatation of plates. But for a large part of a charge or discharge, the internal resistance is constant within very small limits. The method of determining this approsimate value of the internal resistance was as follows:- With the battery about one-fourth discharge, a charging current of ten amperes was sent through it for a period of 2½ minutes and the voltage of the battery observed, accurately, at the switch board terminals of the battery. The charging current was then discontinued and the open circuit voltage of the battery observed. The battery was then discharged with a current of 10 amperes, for 2½ minutes, and the terminal voltage again observed. This procedure was followed for various currents until 60 amperes was reached.

In case of a charging current, the internal resistance of the battery was equal to the difference between the voltage on charge and the open circuit voltage, divided by the

charging current. In case of a discharging current, the internal resistance of the battery was equal to the difference between the open circuit voltage and the voltage on discharge, divided by the discharge current.

The results obtained in this manner included, also, the ohmic resistance of the leads from the cells to the switch board, and the resistance of the switch board plug contacts. In order to obtain the true "virtual resistance" of the battery, this lead and plug resistance must be found and subtracted from the results previously obtained.

It was found that when charging at a 120 ampere rate, there was a difference of 13 volts between the voltage at the switch board and the voltage obtained by adding the voltage given at the terminals of each of the 60 cells. It was evident that this 13 volts was the resistance drop in the leads and plug contacts at the switch board.

When this IR drop, or 13 volts, was divided by the current of 120 amperes, the result was equal to the lead and plug resistance. This lead resistance was equal to .108 ohms, and by subtracting it from the total battery resistance previously found, the true "virtual resistance" of the battery was obtained. An average value of this resistance,figured from the various charge and discharge rates, was found to be .124 ohms.

The values of the resistance were, in each case, slightly higher on discharge than on charge.

INTERNAL RESISTANCE.

I	E Charge	E Open Cir.	E Discharge	R Charge	True R Charge	R Dis-charge	True R Dis-charge
10	124	122.5	120.3	.15	.042	.22	.112
20	129.9	125	120.5	.224	.116	.225	.117
30	133	125.8	117	.239	.131	.28	.172
40	135	125.8	115	.23	.122	.27	.162
50	137.3	126	113	.226	.118	.26	.152
60	139.5	126.3	111.5	.22	.112	.26	.152

R leads = .108 ohms

Drop in Leads = .13 volts on 120 ampere discharge

True Resistance = R on charge - Resistance leads

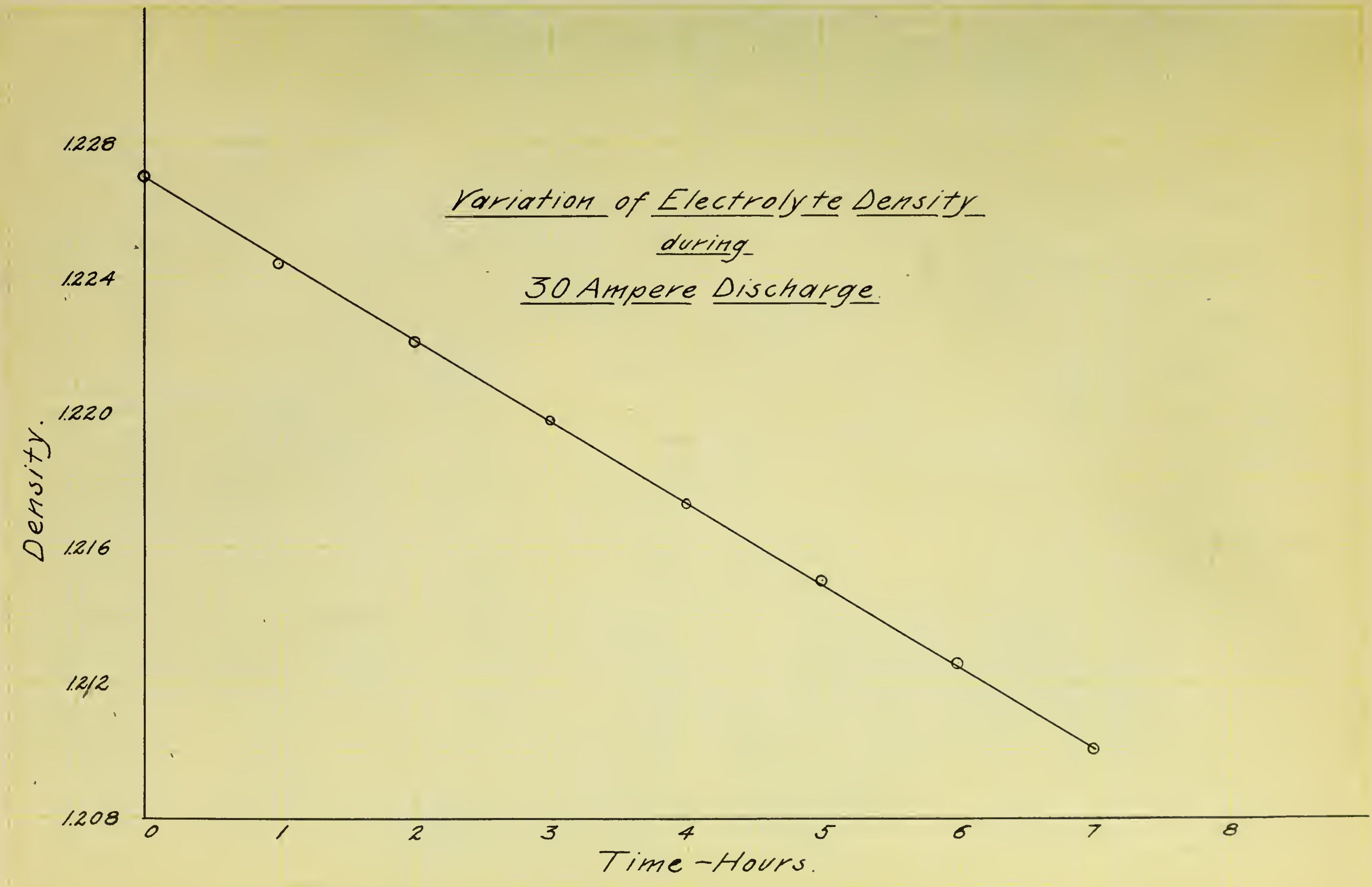
Average Internal Resistance = .124

DENSITY VARIATION OF ELECTROLYTE.

The density of the electrolyte has an important bearing on the operation of the battery and is of great value in indicating the conditions of the separate cells. If it is too high sulphation will occur and the plates are liable to rapid depreciation. The voltage of a battery varies with the density of electrolyte. At a density of 1.24 the electrolyte has a minimum resistance and gives maximum voltage. The electrolytic density varies during charge and discharge. On charge, the SO_3 in combination with the active material and forming the lead sulphate, is given up to the liquid, which therefore gains in density. On discharge the converse takes place; the SO_3 is taken up by the lead and lead peroxide to form sulphate and the density of the liquid decreases. As the electrolyte decreases in density the E.M.F., capacity and conductively likewise decrease and as these should be maintained as high as possible, it follows that the acid density should not fall too low near the end of discharge. It is then evident that the greater the quantity of electrolyte present and entering into chemical action the less will be the change in density. The standard density of electrolyte for full charge with the Gould Storage Battery is 1.225. On discharge this gradually decreased until at end of discharge the density reading was 1.21. The curve plotted between density and time gave a straight line when normal discharge and charge occurred. It was also found that the higher the rates of discharge the less diminution in the density of the electrolyte.

VARIATION OF ELECTROLYTE DENSITY ON 8 HOUR DISCHARGE AND CHARGE.

Time	Density	Time	Density
3.40	1.227	11.00	1.212-
4.40	1.224+	12.00	1.213
5.40	1.222	1.00	1.216-
6.40	1.219+	2.00	1.218
7.40	1.217	3.00	1.220+
8.40	1.215+	4.00	1.223
9.40	1.212+	5.00	1.225
10.40	1.209	6.00	1.227+
		6.40	1.228+


Variation of Electrolyte Density
during
30 Ampere Discharge
Density.
1.228
1.224
1.220
1.216
1.212
1.208
0
1
2
3
4
5
6
7
8
Time-Hours.

CONCLUSION.

Several facts of importance were brought out by this test. In the first place, it is reasonable to suppose that a battery which has been subjected to the usage, which this battery has undergone for a period of over a year, would deteriorate to a certain extent. Yet the results obtained during the test just completed showed an improvement in efficiencies over those obtained in a similar test a year ago. The test showed that the battery was in good condition and that the efficiencies were slightly higher than those guaranteed by the manufacturers, for their battery, when new.

The variation of electrolyte was less than the normal variation for a complete cell of this type, owing to the fact that each cell contains only one half the full number of plates. Hence each cell contains over twice the amount of electrolyte necessary to the normal operation of it. The number of plates may be doubled at any time, thus doubling the capacity of the battery.

Another fact, which was clearly brought out, was the importence of using large copper leads from the cells to the switch board. When the cells were discharging and a current of 120 amperes was flowing, the resistance drop in the leads was 13 volts or approximately 10% of the battery voltage as has already been mentioned. Hence it can be easily seen that with long or small leads to the switch board the drop, especially at high discharge rates, might be a large part of the total

battery voltage.

It would be of interest to conduct a test similar to the foregoing, in two or three years, and by comparing the respective results, determine the rate of deterioration of the battery under the conditions of its use at the University.